Original Article

Injury profile in elite acrobatic gymnasts compared by gender

MERCEDES VERNETTA-SANTANA[1], LEOPOLDO ARIZA-VARGAS[2], MARÍA JOSÉ MARTÍNEZ-PATIÑO[3], JESÚS LÓPEZ-BEDOYA[1]

[1]*Department of Physical Education and Sport, Faculty of Physical Activity and Sport Sciences, University of Granada, Spain*
[2]*Department of Special Didactics, Faculty of Educational Sciences, University of Cordoba, Spain*
[3]*Department of Special Didactics, Faculty of Physical Education and Sport Sciences, University of Vigo, Spain*

ABSTRACT

Acrobatic gymnastics is associated with injury risk. The aim of the study was to gain knowledge on injury incidence, type and severity in acrobatic gymnasts of both sexes. An epidemiologic, descriptive, cross-sectional study was conducted involving 54 gymnasts: 23 males and 31 females aged 14 to 23. The training characteristics (training time: days and hours), as well as the injuries suffered (site, type, severity and moment of injury) were assessed. A total of 89 injuries were recorded. Injury incidence was 9.85/1,000 h of exposure among women and 9.15 among men. The highest percentage of injuries was located in the lower limb, with no significant differences based on sex. Ligament injuries were the most common among women, while tendonitis prevailed among men. The majority of injuries occurred while performing group skills in the technical part of the session (27% during dynamic and 23.6% during static skills), bases suffered a greater number of injuries than tops. It was concluded that muscle and ligament injuries were the most common injury types, the lower limb the most frequently affected body region and moderate the most frequent severity level in both sexes. The variables sex and role were associated with injury incidence.

Keywords: Acrobatic gymnastics; Injury; Gender; Sport medicine.

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Corresponding author. *Department of Special Didactics, Faculty of Educational Sciences, University of Cordoba, Avda. San Alberto Magno s/n, 14004 – Córdoba. Spain.* https://orcid.org/0000-0001-8914-2408
E-mail: lariza@uco.es
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INTRODUCTION

Acrobatic gymnastics (AG) is a gymnastic discipline embedded in the International Gymnastics Federation since 1999 and well established as a competition sport at international level. It is mainly a cooperative sport, where two to four participants interact in a synchronised manner and help each other in order to create figures or human pyramids while having direct contact among them (Vernetta, López-Bedoya, & Gutiérrez, 2008).

During competition, these gymnasts are meant to perform three types of exercises (Purnell, Shirley, Nicholson, & Adams, 2010): balance, dynamic (or tempo) and combined, with specific characteristics. There are also specific morphological profiles depending on the role gymnasts carry out during competition. Tops are the shorter and lighter and perform various static skills supported by the base in cooperative routines, or big acrobatic jumps after propulsion from the base with landing on them again or on the floor (Taboada-Iglesias, Gutiérrez-Sánchez, & Vernetta, 2016). Bases are taller, heavier and have greater fat percentage, since their role is to support the tops.

In order to perform at high level and to meet the high technical demands, gymnasts need to train a large number of hours to be able to include in their routines skills with high degree of difficulty with greatest perfection, with the aim to obtain the best result in competition (Vernetta et al., 2008). The problem arises when fatigue appears while executing those skills, causing imperfections, lack of coordination and, very often, falls. Therefore, injury risk, as well as in other gymnastic sports, can be high (Abalo, Gutiérrez, & Vernetta, 2013a).

According to the study by Purnell et al. (2010), more than half of the gymnasts who practise acrobatic gymnastics have suffered some type of injury during their training, ranging from contractures to bone fractures or muscle tears. Usually the knee or the ankle was involved in the lower limb joint, while the wrist or the shoulder was mostly affected in the upper limb. They occurred most often among girls and boys aged 11 to 15 who bore high training volume.

Additionally, it is important to mention that lumbar spine injuries are also very common. They are generally related to acute or repetitive microtrauma due to overuse, since this is the site of spinal rotation during flexion and extension in many skills that require hypermobility of that region (Micheli & Allison, 1999). Consequently, approximately 50% of acrobatic gymnasts reported pain resulting from degenerative changes in the spine (Anwajler, Wojna, Stepak, & Skolimowski, 2005).

Abalo et al. (2013a) stated that numerous studies have addressed injury incidence and prevalence in more traditional gymnastic sports, such as men's and women's artistic gymnastics or rhythmic gymnastics, while studies involving acrobatic gymnastics are scarce (Grapton, Lion, Gauchard, Barrault, & Perrin, 2013; Purnell et al., 2010; Vernetta, Montosa, & López-Bedoya, 2018).

Given the lack of this type of studies and, especially, the lack of epidemiological studies regarding this sport in the Spanish context, it seems necessary to conduct a study with the aim to gain knowledge on injury incidence, type and severity in elite Spanish gymnasts of both sexes. Besides, it seems also necessary to determine in which part of the session injury incidence is highest and to examine the potential relationships between sex and role, on one hand, and injury variables (severity, type and moment) and training load (hours/day and days/week), on the other.

MATERIAL AND METHOD

Participants

The sample consisted of 54 gymnasts, 23 male and 31 female, who competed at international level and had an average training experience of more than four years (4.36 ± 3.88). The inclusion criteria were: to be associated to a federation, either male or female and to participate in international championships. Table 1 describes the sample characteristics.

Table 1. Descriptive analysis of the sample characteristics (Mean ± Standard deviation).

		Sex		**Role**	
		Male (n = 23)	Female (n = 31)	Base (n = 38)	Top (n = 16)
Age (years)		22.17 ± 4.95	15.19 ± 2.02	19.13 ± 4.55	15.88 ± 5.30
Height (m)		1.71 ± 0.90	1.57 ± 0.70	1.67 ± 0.09	1.53 ± 0.06
Body weight (kg)		66.40 ± 10.60	47.35 ± 10.92	61.77 ± 11.04	40.49 ± 9.02
BMI (kg/m^2)		24.33 ± 7.89	19.44 ± 3.14	21.70 ± 2.08	17.17 ± 2.84
Training hours/day	2	0 (0.0)	1 (1.9)	1 (1.9)	0 (0.0)
	>2	23 (42.6)	30 (55.6)	37 (68.5)	16 (29.6)
Training days/week	3	1 (1.9)	3 (5.6)	4 (7.4)	0 (0.0)
	4	6 (11.1)	14 (25.9)	15 (27.8)	5 (9.3)
	5	12 (22.2)	14 (25.9)	15 (27.8)	11 (20.4)
	6	4 (7.4)	0 (0.0)	4 (7.4)	0 (0.0)

Data of Training hours/day and Training days/week are shown as observed frequency (percentage). BMI = body mass index.

All gymnasts signed an informed consent, which stated the voluntary nature of their participation and the confidentiality of the data contained in the form they would fill in. All procedures followed the guidelines established by the World Medical Association in the Declaration of Helsinki for research involving human subjects and the research followed the Spanish law regarding data protection (Ley Orgánica de Protección de Datos, LOPD).

Methodology and procedure

A descriptive, cross-sectional study was conducted with the aim to analyse gymnasts' injuries.

A retrospective questionnaire was used to collect the data. It had been validated in previous studies involving aerobic gymnastics (Abalo, Vernetta, & Gutiérrez, 2013b) and applied in acrobatic gymnastics, rhythmic gymnastics and tumbling (Rojas, Vernetta, & López-Bedoya, 2015; Vernetta, Montosa, & López-Bedoya, 2016; Vernetta et al., 2018). The questionnaire allowed for collection of information regarding the participants' characteristics, such as sex, age, body weight, height, days and hours of training or use of safety material, as well as about the injuries suffered during the practice of this sport (number, type or nature, site, severity, moment and mechanism).

Severity was defined based on the time of absence from training or competition: minor (absence from at least one day of training), moderate (the gymnast must refrain from training between 8 and 21 days and requires treatment) or severe injuries (the gymnast must refrain from training for more than 21 days and may require hospitalisation (Abalo et al., 2013b).

Injury incidence was calculated using the following formula for training and competition: (number of injuries / hours of exposure) x 1,000 hours (Cupisti, 2007; Purnell et el., 2010; Vernetta et al., 2018). Additionally, body mass index (BMI; kg/m^2) was calculated with the body weight and height.

Statistical analysis

Descriptive data analysis was carried out based on crosstabs. Data independence was checked through Pearson's chi-squared statistic and their association through Eta coefficient (Nominal x Interval – Training days/week * DV), contingency coefficient (Nominal x Nominal – Sex, Role, Training hours/day * DV), DV being Type, Severity, Body region affected and Moment of injury. Mann-Whitney's U test for independent samples was used to analyse injury incidence based on the levels of the variables Sex and Role. The size effects were calculated with the formula $r = \frac{Z}{\sqrt[2]{N}}$.

Differences were considered statistically significant when p < .05. The analyses were performed using the software Statistical Package for the Social Sciences (SPSS) v. 25.0 (SPSS Inc., Chicago, IL).

RESULTS

The injury characteristics (Type, Severity, Body region affected and Moment of injury) are described in Tables 2 and 3, divided by participants' sex and role.

A total of 89 injury reports were collected in this study. The highest percentage of injuries was observed in the base role (f = 69 ≈ 77.5%), compared to the top role (f = 20 ≈ 22.5%).

Table 2. Injury characteristics (type, severity and body region affected), training hours per day and training days per week, divided by participants' sex and role.

		Sex(1)		**Role(2)**		**Total**
		Male	Female	Base	Top	
Type of injury	Sprain	6(13.3)	18(40.9)	14(20.3)	10(50.0)	24(27.0)
	Tendonitis	13(28.9)	2(4.5)	13(18.8)	2(10.0)	15(16.9)
	Contracture	6(13.3)	6(13.6)	9(13.0)	3(15.0)	12(13.5)
	Partial fracture	1(2.2)	4(9.1)	4(5.8)	1(5.0)	5(5.6)
	Fracture	1(2.2)	4(9.1)	5(7.2)	0(0.0)	5(5.6)
	Vertebral rotation	0(0.0)	1(2.3)	1(1.4)	0(0.0)	1(1.1)
	Muscle fatigue	5(11.1)	3(6.8)	6(8.7)	2(10.0)	8(9.0)
	Muscle tear	2(4.4)	1(2.3)	3(4.3)	0(0.0)	3(3.4)
	Dislocation	1(2.2)	1(2.3)	1(1.4)	1(5.0)	2(2.2)
	Periostitis	3(6.7)	1(2.3)	4(5.8)	0(0.0)	4(4.5)
	Pain	1(2.2)	2(4.5)	2(2.9)	1(5.0)	3(3.4)
	Strain	0(0.0)	1(2.3)	1(1.4)	0(0.0)	1(1.1)
	Subluxation	1(2.2)	0(0.0)	1(1.4)	0(0.0)	1(1.1)
	Luxation	3(6.7)	0(0.0)	3(4.3)	0(0.0)	3(3.4)
	Contusion	1(2.2)	0(0.0)	1(1.4)	0(0.0)	1(1.1)
	Low back pain	1(2.2)	0(0.0)	1(1.4)	0(0.0)	1(1.1)
Severity	Minor	14(31.1)	15(34.1)	19(27.5)	10(50.0)	29(32.6)
	Moderate	28(62.2)	17(38.6)	37(53.6)	8(40.0)	45(50.6)
	Severe	3(6.7)	12(27.3)	13(18.8)	2(10.0)	15(16.9)

Body region	Lower limb	18(40.0)	22(50.0)	28(40.6)	12(60.0)	40(44.9)
	Upper limb	15(33.3)	10(22.7)	23(33.3)	2(10.0)	25(28.1)
	Trunk	12(26.7)	12(27.3)	18(26.1)	6(30.0)	24(27.0)
Total		45(100)	44(100)	69(100)	20(100)	89(100)

(1). Data are shown as frequency (percentage within 'Sex'). (2). Data are shown as frequency (percentage within 'Role').

Table 3. Descriptive analysis of the moment of injury depending on the gymnasts' sex and role. Data are shown as frequency (percentage of the total).

		Moment of injury							
		1	2	3	4	5	6	7	8
Sex	Male	3(3.4)	1 (1.1)	9 (10.1)	9 (10.1)	6 (6.7)	15 (16.9)	0	2 (2.2)
	Female	3(3.4)	7 /7.9)	4 (4.5)	4 (4.5)	15 (16.9)	9 (10.1)	1(1.1)	1 (1.1)
	Total	6(6.7)	8(9.0)	13(14.6)	13(14.6)	21(23.6)	24(27.0)	1(1.1)	3(3.4)
Role	Base	6(6.7)	3(3.4)	12(13.5)	11(12.4)	15(16.9)	18(20.2)	1(1.1)	3(3.4)
	Top	0	5(5.6)	1(1.1)	2(2.2)	6(6.7)	6(6.7)	0	0
	Total	6(6.7)	8(9.0)	13(14.6)	13(14.6)	21(23.6)	24(27.0)	1(1.1)	3(3.4)

Moment of injury: 1) Choreography, 2) Warm up, 3) Static individual, 4) Dynamic individual, 5) Static group, 6) Dynamic Group, 7) Strength and conditioning, and 8) Competition.

Degree of association of the variables Sex and Role with the factors Type of injury, Severity, Body region affected, Moment of injury, Training hours per day and Training days per week

According to the crosstab analysis (Table 4), participants' Sex was related with Type of injury (χ^2(15, N = 89) = 27.826, p = .023), Severity (χ^2(2, N = 89) = 8.113, p = .017), Moment of injury (χ^2(7, N = 89) = 15.027, p = .036) and Training days per week (χ^2(3, N = 89) = 25.678, p = .000). The association indices related to chi-squared statistic, i.e. the contingency coefficient for the variables Type, Severity and Moment of injury, and Eta coefficient for the variable Training days per week, confirmed the previous results.

Regarding Type of injury, the highest incidence corresponded to sprains (f = 24 ≈ 27%). 40.9% (f = 18) of the female gymnasts suffered this injury, compared to 13.3% (f = 6) of the male gymnasts. By contrast, 28.9% of the male gymnasts suffered tendonitis, while only 4.5% (f = 2) of the females did. This was the second most frequent pathology, affecting 15.6% (f = 15) of the sample (Table 2).

As regards Severity, a moderate injury was observed in 50.6% (f = 45) of the sample, incidence being higher among male (f = 28 ≈ 62.2%) than female gymnasts (f = 17 ≈ 38.6%). To the contrary, 27.3% (f = 12) of the female gymnasts were affected by severe injuries, compared with the lower incidence observed among males (f = 3 ≈ 6.7%). This was the least frequent injury severity level, affecting only 16.9% of the sample.

Furthermore, it must be highlighted that only 42.2% (f = 19) of the male athletes attended training six days a week, in spite of the fact that the largest group of participants trained five days a week (f = 35 ≈ 39.3%). However, the greatest difference between male and female gymnasts lay in the group who trained four hours a day (f = 8 ≈ 17.8%; f = 20 ≈ 45.5% respectively).

When focusing on the participants' role, it was observed that 100% of the tops trained between four (f = 6 ≈ 30%) and five (f = 14 ≈ 70%) days a week, compared with 62.3% of the bases (f = 22 ≈31.9% and f = 21 ≈ 30.4%, four and five training days a week, respectively). Only 27.5% (f = 19) of the bases trained six days a week.

Table 4. Pearson's chi-squared test and association coefficient for the variables Sex and Role and the factors Type of injury, Severity, Body region affected, Moment of injury, Training hours per day and Training days per week.

Dependent variables		Sex (N = 89)	Role (N = 89)	Male * Role (N = 45)	Female * Role (N = 44)
Type of injury	Chi-squared	27.826	12.756	17.374	8.532
	Df	15	15	13	11
	p	.023	.621	.183	.665
	Association	.289(b) *p* = .017	.354(b) *p* = .621	.528(b) *p* = .183	.403(b) *p* = .665
Severity	Chi-squared	8.113	3.689	2.761	4.670
	Df	2	2	2	2
	p	.017	.158	.251	.097
	Association	.202(b) *p* = .290	.200(b) *p* = .158	.200(b) *p* = .251	.310(b) *p* =.097
Body region	Chi-squared	1.389	4.395	5.673	4.023
	Df	2	2	2	2
	p	.499	.111	.059	.134
	Association	.124(b) *p* = .499	.217(b) *p* = .111	.335(b) *p* =.059	.289(b) *p* = .134
Moment of injury	Chi-squared	15.027	30.012	(*)	(*)
	Df	7	21		
	p	.036	.092		
	Association	.380(b). *p* = .036	.502(b). *p* = 0.92		
Training hours/day	Chi-squared	3.175	.900	(*)	1.502
	Df	1	1		1
	p	.075	.343		.220
	Association	.186(b) *p* = .075	.100(b) *p* = .343		.182(b) *p* = .220
Training days/week	Chi-squared	25.678	13.726	7.680	4.880
	Df	3	3	3	2
	p	.000	.003	.053	.087
	Association	.475(a)	.025(a)	.0146(a)	.333(a)

(a). Association coefficient Nominal or Ordinal x Interval: Eta.(b). Association coefficient Nominal x Nominal: Contingency coefficient. (*) Calculation was not possible. At least one variable in each two-way table used to calculate the association measures was a constant.

Association of the variables Training days per week and Training hours per day with Type of injury and Severity

Chi-squared statistic did not reveal any significant association between the number of Training days per week and the Type of injury (χ^2(45, N = 89) = 46.954, p = .392) or its Severity (χ^2(6, N = 89) = 9.560, p = .144).

While the variable Training hours per day did not show association with Type of injury (χ^2(15, N = 89) = 4.059, p = .998) either it did with Severity (χ^2(2, N = 89) = 15.316, p = .000; *Eta* = .315).

All minor (f = 29) and moderate (f = 45) injuries affected gymnasts who trained for more than two hours a day. By contrast, from all the severe injuries reported (f = 15 ≈ 16.9%), only 3.4% (f = 3) affected gymnasts who trained for less than two hours a day, while the remaining 13.5% (f = 12) corresponded to athletes who trained longer than that.

Injury incidence analysis

Mann-Whitney's U test did not yield any statistically significant differences in the distribution of the variable Injury incidence based on the participants' sex (U = 53.50, p = .796, r = .06). By contrast, the same test showed that Injury incidence was higher among bases (*Mdn* = 13.3) than among tops (*Mdn* = 7.7, U = 22.0, p = .035, r = .489).

Based on the variables Sex and Role, Mann-Whitney's U test did not reveal any statistically significant differences in the distribution of injury incidence depending on the role performed by male (U = 4.5, p = .095, r = .545) or female gymnasts (U = 6.5, p = .222, r = .408).

DISCUSSION

The present study on the injuries suffered by elite acrobatic gymnasts of both sexes has yielded the following findings: a) injury incidence was higher during training than during competition; b) the greatest percentage of injuries affected gymnasts performing the base role, this percentage being similar among women and men; c) the most frequently affected body region was the lower limb, ligament injuries (sprains) being the most common among women and tendonitis among men; d) the majority of injuries were either moderate or minor; e) the highest percentage of injuries occurred during the technical part of the training session, especially during dynamic and static cooperative skills, both to bases and tops; f) regarding severity, moderate injuries were the most common among male gymnasts, while female gymnasts were more affected by severe injuries than males.

No previous study had analysed injury incidence in Spanish elite gymnasts of this discipline of both sexes. This emphasises the importance of these results with regard to their prevention.

The few studies that have examined injuries in this gymnastic discipline in other countries revealed results in agreement with ours in many aspects (Grapton et al., 2013; Purnell, 2010; Rego, Reis, & Oliveira, 2007). Thus, in the present study, injury incidence was higher during training (96.6%) than during competition (3.4%). This is in line with the results obtained for acrobatic gymnasts between 8 and 13 years old (Purnell et al., 2010) and for Spanish female acrobatic gymnasts aged 12 to 18 (Vernetta et al., 2018). These data confirm the findings from other gymnastic disciplines, where the highest injury incidence occurred during training (Abalo et al., 2013b; Vernetta et al., 2016). These results should warn managers about the advantage of regulating training load, particularly in adolescent gymnasts between 11 and 15 years old. These are more vulnerable to injury risk when training volume exceeds a certain threshold, as they are undergoing a critical period due to fast growing during the adolescence (Purnell et al., 2010).

The average injury rate among female gymnasts was 9.85 per 1,000h of exposure including competition and training, similar to the 9.37 obtained for gymnasts from the National Collegiate Athletic Association (Westermann, Giblin, Vaske, Grosso, & Wolf, 2015). Male gymnasts showed an average injury incidence of 9.15, slightly higher than the 8.78 reported for artistic gymnasts (Westermann et al., 2015). It has not been possible to establish any similarities with values reported for acrobatic gymnastics, since there are no previous studies involving elite gymnasts of both sexes.

No significant differences were detected between sexes as regards the number of injuries, in accordance with Rodríguez-Camacho, Correa-Mesa, Camargo-Rojas, & Correa-Morales (2016). Nonetheless, bases presented higher injury incidence than tops (77.5% for bases vs. 22.5% for tops), as confirmed by the chi-squared (Table 2), and in line with the results from Vernetta et al. (2018), where bases suffered significantly more injuries than tops.

This fact can be related to the tops' younger age, lower body mass and shorter height, confirming the findings by other studies that indicate that those gymnasts of younger age and lower body mass and BMI suffered fewer injuries due to their biological maturation (Irrutia-Amigó, Pons-Sala, Busquets-Faciabén, Evrard, Carrasco-Marginet, & Rodríguez-Zamora, 2009; Rodríguez-Camacho et al., 2016). These data are also in agreement with Caine and Nasser (Caine & Nassar, 2005), who stated that gymnasts of greater height and body mass had higher injury risk, since they bear greater impacts on their body structures, such as tendons and joints.

All morphological measures were larger in bases compared with tops, because of the specific role performed by each of them3. Mean BMI was 21.70 ± 2.08kg/m^2 for bases and 17.17 ± 2.84kg/m^2 for tops, both values being slightly higher than those reported by Taboada et al. (2016): 20.28 kg/m^2 and 16.40 kg/m^2, respectively.

Besides, ligament and tendon injuries were the most frequent injury types, in line with other studies on acrobatic gymnastics (Grapton et al., 2013; Purnell et al., 2010; Vernetta et al., 2018).

The results from previous studies on acrobatic gymnastics regarding the body region affected by the injury were also confirmed (Grapton et al., 2013; Purnell et al., 2010; Vernetta et al., 2018), the lower limb being the most frequently affected body region in the whole sample (44.9%), mostly by ligament injuries. The same occurred in other gymnastic disciplines, where ligament and soft-tissue injuries were the most common in the lower limb (Abalo et al., 2013b; Marsall, Marshall, Covassin, Dick, Lawrence, & Agel, 2007; Rodríguez-Camacho et al., 2016; Vernetta et al., 2016).

The ankle and the knee were the most affected anatomic sites, as it happened to female acrobatic gymnasts (Purnell et al., 2010; Vernetta et al., 2018) and to male artistic gymnasts on floor apparatus, where ankle and knee injuries presented the highest incidence, due to the impact born by these joints while landing from acrobatic skills (Harringe & Renströn, 2007; Kirialanis, Malliou, Beneka, & Giannakopoulos, 2003). Kirilanis et al. (2003) found that 71% of the injuries happened during the landing phase of acrobatic skills, since the load supported by gymnasts on the contact with the ground is 5 to 17.5 times their body weight, what makes them vulnerable to injuries.

The second most frequently injured body region was the upper limb, mainly the wrists (28.1%), as found in acrobatic gymnastics (Purnell et al., 2010; Rego et al., 2007) (24.1% and 34.7%, respectively), or in artistic and aerobic gymnastics (Abalo et al., 2013b; Caine & Nassar, 2005). In all these gymnastic sports, the musculoskeletal system is exposed to high loads, which must be distributed through the elbow and wrist joints when the body is supported by the upper limbs (Farana, Jandacka, Uchytil, Zahradnik, & Irwin, 2017). In fact, gymnasts must support their own body weight on these joints during individual routines, and bases must support tops' weight during group routines (Abalo et al., 2013b; Grapton et al., 2013; Marsall et al., 2007; Purnell et al., 2010; Rego et al., 2007; Vernetta et al., 2018).

The third most affected body region in our study was the trunk (27.0%), particularly the low back, in keeping with previous results obtained in acrobatic (Purnell et al., 2010; Vernetta et al., 2018) and rhythmic gymnasts (Vernetta et al., 2016). Actually, both disciplines require executing many different positions with maximal spine flexion or extension, producing low back pain associated with acute or repetitive microtrauma due to overuse.

As prevention measures, it would be advisable to include core strengthening exercises in the training session to improve the stability of the region, as well as to use a back support belt with the aim to protect the back during the execution of positions that require maximal flexibility (Vernetta et al., 2018; Vidal, Borrás, Ortega, Cantallops, Ponseti, & Palou, 2011).

Likewise, it would be desirable to promote greater medical supervision and multidisciplinary intervention (including managers, strength trainers, choreographers, doctors and physiotherapists) in clubs, so that young gymnasts can practise under optimal health and safety conditions and, therefore, extend their careers as international elite athletes.

As regards severity, most injuries registered in the whole sample were either moderate (50.6%) or minor (32.6%), meaning that 83.2% of the gymnasts needed between one and two weeks to recover. This agrees with Purnell et al. (2010) and Vernetta et al. (2018), who reported that most acrobatic gymnasts had to refrain from training for less than 11 days. Many gymnasts followed an active recovery, including cryotherapy, functional treatment with bandage, rest of the injured region and massage therapy to accelerate recovery (Vernetta et al., 2018).

If we analyse the type of injury based on sex, female gymnasts presented highest incidence of ligament injuries (40%), mainly located in the lower limb (ankle and knee), while male gymnasts suffered mostly tendon injuries (28%), mainly to the upper limb ($f = 10 \approx 76.9\%$). These results are in keeping with Chilvers, Donahue, Nassar, & Manoli (2007) who reported that female artistic gymnasts were particularly prone to ankle sprains and internal knee injuries, while the most common injuries among male gymnasts occurred to the wrist and shoulder. These were associated with the specific work on the different apparatus, which represented higher demands for the upper limb.

In our study, a possible explanation could be that there were a higher number of male bases than tops, and they supported the top's weight with their arms during many skills, producing greater load on these joints.

Similarly, our data confirm previous epidemiological studies involving female artistic gymnasts that reported the highest injury incidence to the lower limb ($f = 22 \approx 50\%$) (Caine & Nassar, 2005; Hoshi, Pastre, Vanderlei, Netto Júnior, & Bastos, 2008; Kirialanis et al., 2003).

Statistical difference between sexes was found in injury severity (Table 4). Moderate injuries were more frequent among men, while women suffered more severe injuries than men. This agrees with Westermann et al. (2015), who proved that severe injury incidence was higher among female than among male gymnasts.

In our study it was noteworthy that, despite the fact that severe injuries were the least frequent, three of them affected young gymnasts who trained less than two hours a day. In this regard, Meeusen et al. (2013) suggested that biological maturation was related to injury incidence and severity, what is in line with our study, where female gymnasts were adolescents aged 15.19 ± 2.02 on average, in contrast to male gymnasts, aged 22.17 ± 4.95.

Regarding the moment of the session when injuries appeared, the highest percentage of injuries occurred during the technical part, mostly during dynamic group skills (27%), followed by dynamic skills (23.6%), with no significant differences between sexes. These data are in line with other studies on this discipline (Purnell et al., 2010; Vernetta et al., 2018), other gymnastic disciplines and even other similar sports such as cheerleading, where skills are performed following a choreography including elevations, pyramids and throws from some participants to others (Shields & Smith, 2011). The moment of the session with lowest injury incidence was strength training.

The highest injury incidence among tops affected the ankle and it was due to bad foot landing during dynamic group routines (30.23%). This is in keeping with the study on acrobatic gymnastics (Vernetta et al., 2018), as well as with others involving artistic gymnasts, where landing (last stabilisation phase of the acrobatic skill) was considered to be the most likely phase for injuries to occur (Micheli & Allison, 1999; Nunomura, Pires, & Carrara, 2009).

The highest injury incidence among bases was found at muscular level and was produced by the overuse during static group routines, due to the long time spent by these gymnasts supporting tops during balance positions, applying high percentages of static strength. Furthermore, the technical perfection demanded in these routines needs a lot of repetition during training, what leads to overuse, muscle fatigue and decreased neuromuscular coordination, factors that may increase injury risk (Harringe & Renströn, 2007).

Consequently, it seems important to increase the preventive measures, emphasising a progressive and safe learning process of these movements, with greater control of the training load (volume and intensity) and focusing on quality above quantity. Not following these recommendations can easily make acute injuries such as simple back pain become chronic (Purnell et al., 2010).

Lastly, it must be highlighted that all gymnasts from this study trained on standard surfaces, mats being the most widely used safety material, often combined with wrist and/or ankle braces. The use of mats by quartets was widespread, which is logical and reasonable given the high level of difficulty introduced by height in dynamic or static group routines. In fact, even the Code of Points allows for its use during competition (Purnell et al., 2010).

Although, in general, this study has yielded interesting results, they must be taken with caution, given several limitations, the most relevant one being the injury recording method and its design. In this regard, despite other similar studies on gymnastic sports having used the same questionnaire with satisfactory results, it would be advisable to include expert practitioners (doctors, physiotherapists) in the future to record injuries in order to get more accurate data. Besides, although the cross-sectional design provided evidence of association, it would be interesting to conduct longitudinal studies in the future with the aim to confirm causal relationships.

Nevertheless, one of the strengths of the present study lies on opening this research line in this gymnastic discipline in Spain, providing relevant information on the epidemiology of injuries in this sport in gymnasts of both sexes. Future studies will address aims such as, firstly, to solve the aforementioned limitations, and secondly, to apply different prevention programmes that may reduce injury risk factors in such a recent discipline in our country, where competition only started in 2004.

CONCLUSIONS

In conclusion, the most affected body region was the lower limb, with highest incidence of ligament injuries (sprains). Technical training was the part of the session when the highest percentage of injuries occurred, mostly during dynamic and static cooperative skills, both among bases and tops. The majority of injuries were moderate in both sexes. The variables sex and role were associated with injury incidence. Bases suffered a larger number of injuries than tops.

According to the results obtained, injury prevention for these gymnasts should focus on the landing phase of the different skills through muscle pre-activation exercises (Chassé, Fergusson, & Chen, 2014; Vernetta et al., 2018). It should also include additional preventive work with ankle proprioceptive exercises (Vernetta et al., 2018; Rodríguez-Camacho et al., 2016), during training, given that ankle sprain was the most prevalent injury type in this study.

Lastly, further studies involving as many Spanish participants of this discipline as possible (of different age groups, levels and competition modalities) seem necessary in order to gain knowledge on this matter and to be able to compare groups, leading to more global conclusions.

AUTHOR CONTRIBUTIONS

Vernetta-Santana, V. contributed to the design and implementation of the research, and to the writing of the manuscript. Ariza-Vargas, L. processed the experimental data, performed the analysis of the results, drafted the manuscript and supervised the findings of this work. Martínez-Patiño, M.J. contributed to the implementation of the research, supervised the Project. López-Bedoya, J. contributed to the design and implementation of the research, supervised the Project. All authors discussed the results and contributed to the final manuscript.

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REFERENCES

Abalo, R., Gutiérrez, A., & Vernetta, M. (2013a). Aerobic Gymnastic Injuries. Review article. Int J Med Sci Phys Educ Sport, 13(49), 183-198.

Abalo, R., Vernetta, M., & Gutiérrez, A. (2013b). Analysis of the lesional incidence in the spanish gymnastics elite aerobic competition. Rev Bras Med Esporte, 19(5), 375-8.

Anwajler, J., Wojna, D., Stepak, A., & Skolimowski, T. (2005). The influence of sports acrobatic training on the range of mobility of the spine and the upper and lower extremities. Polish Journal of Physiotherapy, 5(1), 57-64.

Caine, D. J., & Nassar, L. (2005). Gymnastics injuries. Med Sport Sci (48), 18-58. Karger Publishers. https://doi.org/10.1159/000084282

Chassé, M., Fergusson, D. A., & Chen, Y. (2014). Body mass index and the risk of injury in adults: a cross-sectional study. Int J Obesity, 38(11), 1403. https://doi.org/10.1038/ijo.2014.28

Chilvers, M., Donahue, M., Nassar, L., & II, A. M. (2007). Foot and ankle injuries in elite female gymnasts. Foot Ankle Int, 28(2), 214-218. https://doi.org/10.3113/FAI.2007.0214

Cupisti, A., D'Alessandro, C., Evangelisti, I., Umbri, C., Rossi, M., Galetta, F., ... & Piazza, M. (2007). Injury survey in competitive sub-elite rhythmic gymnasts: results from a prospective controlled study. J Sports Med Phys Fitness, 47(2), 203-7.

Farana, R., Jandacka, D., Uchytil, J., Zahradnik, D., & Irwin, G. (2017). The influence of hand positions on biomechanical injury risk factors at the wrist joint during the round-off skills in female gymnastics. J Sports Sci, 35(2), 124-129. https://doi.org/10.1080/02640414.2016.1158414

Grapton, X., Lion, A., Gauchard, G. C., Barrault, D., & Perrin, P. P. (2013). Specific injuries induced by the practice of trampoline, tumbling and acrobatic gymnastics. Knee Surg Sports Traumatol Arthrosc, 21(2), 494-499. https://doi.org/10.1007/s00167-012-1982-x

Harringe, M. L., Renström, P., & Werner, S. (2007). Injury incidence, mechanism and diagnosis in top-level teamgym: a prospective study conducted over one season. Scand J Med Sci Sports, 17(2), 115-119.

Hoshi, R. A., Pastre, C. M., Vanderlei, L. C. M., Netto Júnior, J., & Bastos, F. D. N. (2008). Lesões desportivas na ginástica artística: estudo a partir de morbidade referida. Rev Bras Med Esporte, 4, 440-445. https://doi.org/10.1590/S1517-86922008000500008

Irrutia-Amigó, A., Pons-Sala, V., Busquets-Faciabén, A., Evrard, M.M., Carrasco-Marginet, M., & Rodríguez-Zamora, L. (2009). Talla, peso, somatotipo y composición corporal en gimnastas de élite españolas (gimnasia rítmica) desde la infancia hasta la edad adulta. Apunts. Educ. Fís. Deporte, 1(95), 64-74.

Kirialanis, P., Malliou, P., Beneka, A., & Giannakopoulos, K. (2003). Occurrence of acute lower limb injuries in artistic gymnasts in relation to event and exercise phase. Br J Sports Med, 37(2), 137-139. https://doi.org/10.1136/bjsm.37.2.137

Marsall, S.W., Marshall, S.W., Covassin, T., Dick, R., Lawrence, G.N., & Agel, J. (2007). Descriptive epidemiology of collegiate women's gymnastics injuries: National Collegiate Athletic Association Injury Surveillance System, 1988 - 1989 through 2003 - 2004. J Athl Train, 42(2), 234-40.

Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., ... & Urhausen, A. (2013). Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. Med Sci Sport Exer, 45(1), 186-205. https://doi.org/10.1249/MSS.0b013e318279a10a

Micheli, L.J., & Allison, G. (1999). Lumbar spine injury in the young athlete. Rev Bras Med Esporte, 5, 59-65. https://doi.org/10.1590/S1517-86921999000200005

Nunomura, M., Pires, F. R., & Carrara, P. (2009). Análise do treinamento na ginástica artística brasileira. Rev Bras Cienc Esporte, 31(1).

Purnell, M., Shirley, D., Nicholson, L., & Adams, R. (2010). Acrobatic gymnastics injury: Occurrence, site and training risk factors. Phys Ther Sport, 11(2), 40-46. https://doi.org/10.1016/j.ptsp.2010.01.002

Rego, F., Reis, M., & Oliveira, R. (2006). Lesões em ginastas portugueses de competição das modalidades de trampolins, ginástica acrobática, ginástica artística e ginástica rítmica na época 2005/2006. Análise, 21(1), 21-27.

Rodríguez-Camacho, D.F., Correa-Mesa, J.F., Camargo-Rojas, D.A., & Correa-Morales, J.C. (2016). Prevalence of injuries in gymnasts from the Gymnastics League of Bogotá, D.C. Revista de la Facultad de Medicina, 64, S85-91. https://doi.org/10.15446/revfacmed.v64n3Sup.50829

Rojas, N.A., Vernetta, M., & Lopez-Bedoya, J. (2015). Características de las lesiones deportivas de los gimnastas de competición de tumbling. Arch Med Dep, 32, 215-22.

Shields, B. J., & Smith, G. A. (2011). Epidemiology of strain/sprain injuries among cheerleaders in the United States. Am J Emerg Med, 29(9), 1003-1012. https://doi.org/10.1016/j.ajem.2010.05.014

Taboada-Iglesias, Y., Gutiérrez-Sánchez, A., & Vernetta, M. S. (2016). Anthropometric profile of elite acrobatic gymnasts and prediction of role performance. J Sports Med Phys Fit, 56(4), 433-442.

Vernetta, M., López-Bedoya, J., & Gutiérrez, A. (2008). La Creatividad en la Gimnasia Acrobática. In: Martínez A, Díaz P (Comp). Creatividad y Deporte. Consideraciones teóricas e investigaciones breves (pp. 133-154). Sevilla: Wanceulen Editorial Deportiva.

Vernetta, M., Montosa, I., & López-Bedoya, J. (2016). Análisis de las lesiones deportivas en jóvenes practicantes de gimnasia rítmica de competición en categoría infantil. Rev Andal Med Dep, 9(3), 105-109. https://doi.org/10.1016/j.ramd.2015.11.001

Vernetta, M., Montosa, I., & López-Bedoya, J. (2019). Lesiones en jóvenes gimnastas femeninas de acrobática de la élite nacional. Rev iberoam cienc act fís deporte, 7(3), 71-84. https://doi.org/10.24310/riccafd.2018.v7i3.5542

Vidal, J., Borras, P. A., Ortega, F. B., Cantallops, J., Ponseti, X., & Palou, P. (2011). Effects of postural education on daily habits in children. Int J Sports Med, 32(4), 303-308. https://doi.org/10.1055/s-0030-1270469

Westermann, R. W., Giblin, M., Vaske, A., Grosso, K., & Wolf, B. R. (2015). Evaluation of men's and women's gymnastics injuries: a 10-year observational study. Sports health, 7(2), 161-165. https://doi.org/10.1177/1941738114559705